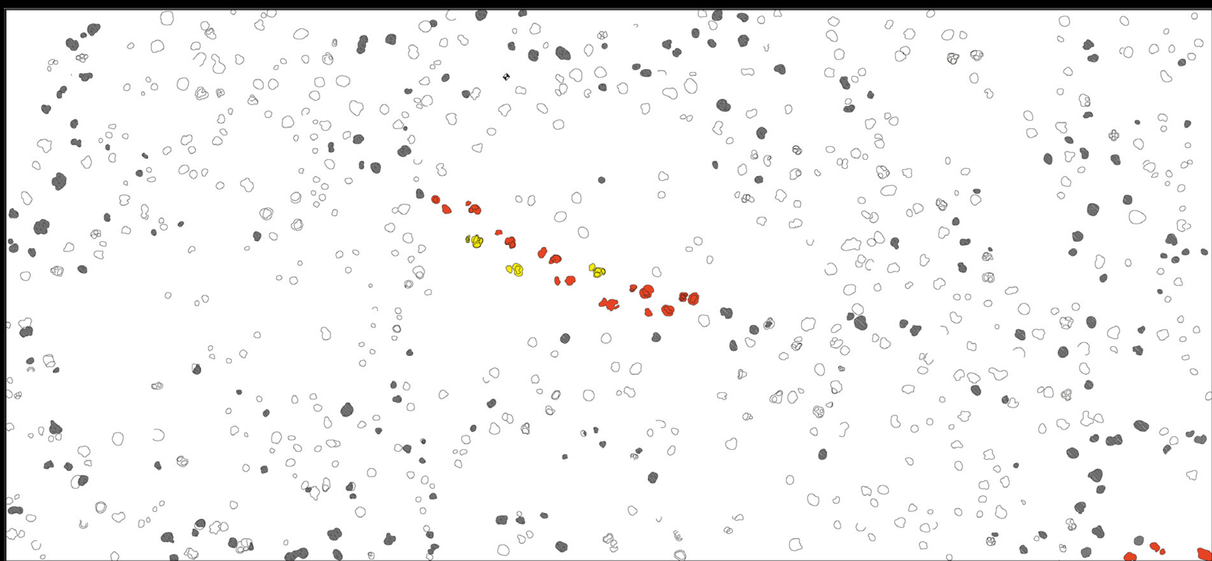
Geological Field Trips and Maps



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Geothematic map of the Altamura dinosaur tracksite (early Campanian, Apulia, southern Italy)

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Cover page Figure
Cover page Figure: Panoramic view of the Altamura track-bearing surface and close-up of the geothematic map, showing the ACDL99/3 trackway.

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Abstract

In 2019 a multidisciplinary study of the Altamura dinosaur tracksite (Apulia, southern Italy; early Campanian) was carried out to meticulously document its geological and palaeontological features. The goal was to pave the way for projects aimed at long-term conservation and valorisation of the geo-palaeontological heritage. For this purpose, a mapping of the whole track-bearing surface was performed, which led to the production of the first geothematic map (1:200) of the whole ichnosite. During the field activities, the surface was subdivided into 34 distinct sectors. For each sector, the work started with accurate manual and mechanical cleaning of the surface (industrial vacuum cleaner). The ichnological survey was carried out using standard methods (interpretative drawings with chalks to highlight outline and morphological features of each track). This approach was combined with close-range photogrammetry to obtain detailed 3D models of the best-preserved specimens. Finally, each sector was surveyed through aerial-based photogrammetry by means of sUAS (small Unmanned Aerial System). The aerial survey allowed us to gain a high-resolution and georeferenced orthophoto processed by using specific software. The field ichnological drawings occurring on each orthophoto were then traced and vectorised. The final step was the overlapping of each digitised sector and the processing of the tracksite map. The products of our study (geothematic map and 3D models of dinosaur tracks) highlight the extraordinary richness of the Altamura tracksite (26,000 footprints and 12 distinct trackways), confirming the high impact of new methodologies (close-range and aerial-based photogrammetry) as useful tools both for ichnological studies and future activities of public fruition of the geosite.

Keywords: dinosaur footprints, Late Cretaceous, Apulia Carbonate Platform, Aerial and Close-range Photogrammetry, sUAS – small Unmanned Aerial System.

Introduction

The Altamura dinosaur tracksite (Metropolitan City of Bari, Apulia, southern Italy; Fig. 1) was identified in May 1999 by the geologists M. Sarti and M. Claps who noted thousands of impressions on the working surface of the "Cava Pontrelli" quarry, during a geological survey for oil exploration. Impressions soon appeared neither randomly distributed nor so regularly (geometrically) spaced to be considered induced by physical (sedimentary) dynamics or anthropic activities. The two discoverers hypothesised that those impressions might be tetrapod footprints and they asked the ichnologists team of the Sapienza University of Rome, headed by U. Nicosia, who immediately confirmed they were dinosaur tracks.

Since June 1999, the track-bearing horizon was thus the subject of repeated ichnological and geological studies whose results were published in various papers and in a Ph.D. Thesis (Nicosia et al., 1999a; 1999b; Petti, 2006). Four ornithopod trackways were recognised and described. One of them, the trackway ACDL99/3, led to the establishment of the new ichnotaxon *Apulosauripus federicianus*, attributed to a hadrosaurid trackmaker (Nicosia et al., 1999b). During the first ichnological surveys on the quarry surface, both traditional methods (see Leonardi, 1987; Thulborn, 1990) and balloon aerial photogrammetry were used, to gain an overview of the dinoturbated surface and to estimate the degree of trampling (i.e., the numbers of dinosaur footprints per unit area; Lockley and Conrad, 1989). Only small portions of the surface were mapped, mainly those with clear dinosaur trackways. Based on the relative size of the areas with a high and low degree of trampling, Nicosia and co-authors estimated a total number of footprints ranging from 25,000 to 30,000 for the entire quarry area (Nicosia et al., 1999b; Petti, 2006).

The footprint-bearing layer was preliminarily attributed to early Santonian by Nicosia et al. (1999b). A Santonian-early Campanian age was inferred by Perugini and Ragusa (2004) and Perugini et al. (2005), based on strontium isotope stratigraphy and benthic foraminiferal assemblages. This chronological attribution was broadly supported by the occurrence of taxa such as *Murgeina apula* (Luperto-Sinni 1968), *Rotalispira scarsellai* (Torre 1967), *Scandonea samnitica* De Castro 1971, *Moncharmontia apenninica* (De Castro 1966), and *Accordiella conica* Farinacci 1962 throughout their measured stratigraphic section, and *Murciella* cf. *cuvillieri* in its upper part, about 18 m above the track horizon.

Several other dinosaur ichnosites were identified in Apulia after the discovery of the Altamura palaeosurface (Fig. 1): Mattinata (Kimmeridgian-Tithonian in age; Conti et al., 2005); Borgo Celano (late Hauterivian-early Barremian; Petti, 2006; Petti et al., 2008); Bisceglie (Aptian; Sacchi et al., 2009; Petti et al., 2010); Molfetta (late Aptian-early Albian; Fanti et al., 2014; Petruzzelli, 2017; Petti et al., 2018) and Lama Balice (late Albian; Petruzzelli et al., 2019). These palaeontological localities, of different Jurassic and Cretaceous ages, record a rich dinosaur biodiversity in the Apulia region, due to the occurrence of theropod, ankylosaur and sauropod tracks (see Petti et al., 2020 for a review).

Among these ichnosites, the Altamura site has thus proved to be one of the most important and spectacular case studies in the world, for the incredible number of footprints imprinted on a single surface (Andreassi et al., 1999).

Unfortunately, for reasons related to disputes between the ownership of the quarry and Authorities, the study and preservation of the palaeosurface were suspended until 2019.

Twenty years after the discovery of the site, in the spring of 2019, a new multidisciplinary study of the

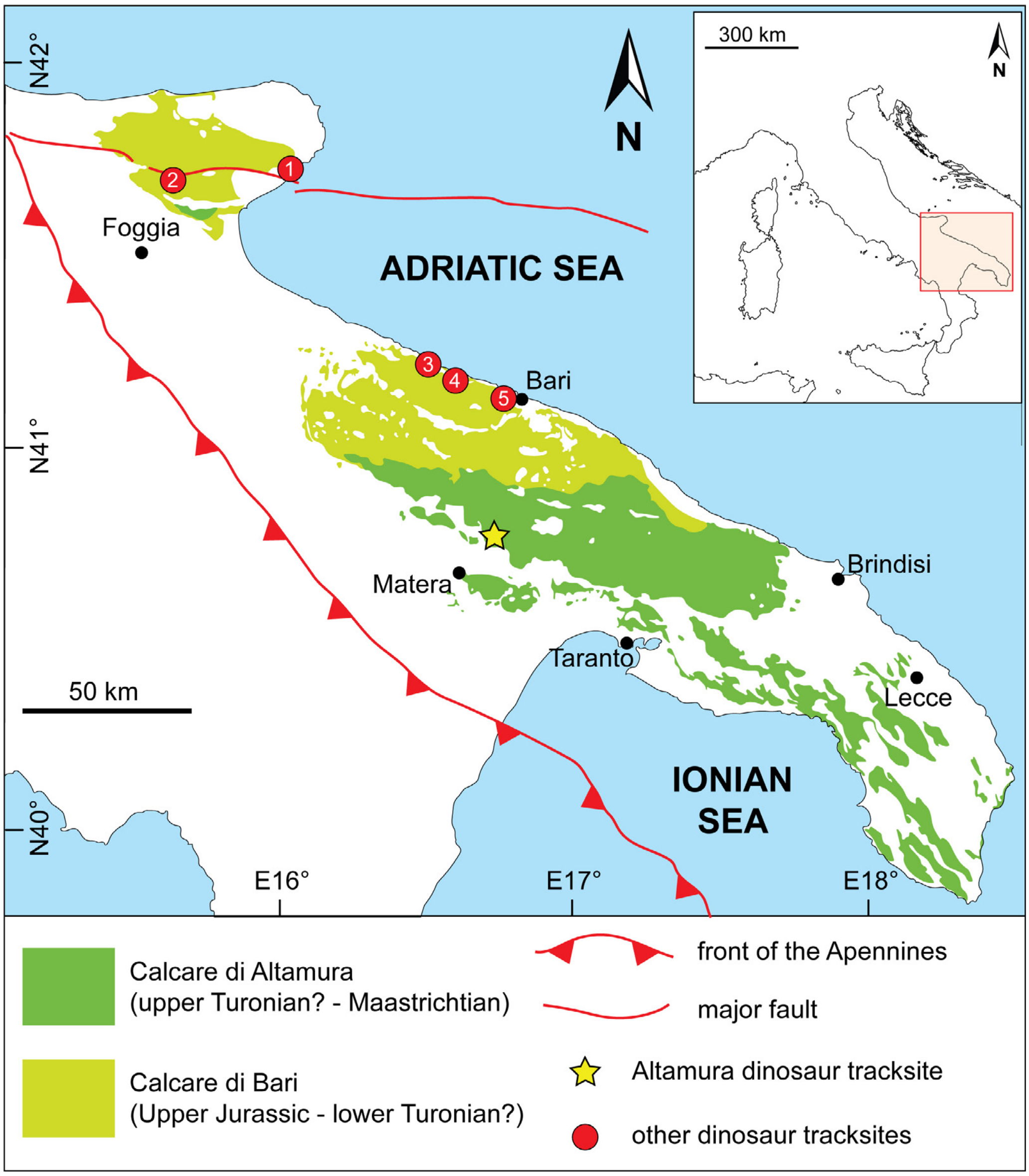

Fig. 1 - Location map of the Altamura tracksite and geological sketch-map of Upper Jurassic-Cretaceous deposits cropping out in Apulia (modified after Festa et al., 2018). Tracksites in red circles: 1) Mattinata; 2) Borgo Celano; 3) Bisceglie; 4) Molfetta; 5) Lama Balice.

ichnosite began (AA.VV., 2020). The aim of the new project was to pave the way for the long-term protection and conservation of dinosaur footprints and for future public fruition of the ichnosite.
The scientific project involved geologists and palaeontologists of the University of Bari Aldo Moro, Muse - Science Museum of Trento, and Sapienza - University of Rome. The technical aspects were handled by the Environmental Surveys S.r.l., a Spin-off of the University of Bari, mainly focused on the geomatics surveys.
A new geological and structural map of the quarry and of the surrounding area was produced together with a detailed lithostratigraphy of the outcropping succession. All the dinosaur tracks and trackways were thoroughly investigated using the most advanced technology and methods (Mallison and Wings, 2014; Petti et al., 2018 and reference therein).
The purpose of this paper, beyond the ichnological analysis and results, is to present the first geothematic map of the whole Altamura ichnosite in which all the thousands of footprints are figured and georeferenced.

Methods and techniques

The ichnological survey was carried out from May to September 2019. Firstly, the whole dinoturbated surface was computed starting from the aerial images available on Google Earth. An area of 14,000 m^2 was estimated for the track-bearing surface, within an overall surface of 17,500 m^2 (Fig. 2). The whole surface was then subdivided into 34 sectors, most of which of about 500 m^2.
Most of the sectors (1 to 4 and 8 to 21, 2a, 3a, 4a) were analysed in detail, whereas the remaining ones were detected randomly, focusing on a restricted number of dinosaur footprints. The work plan followed

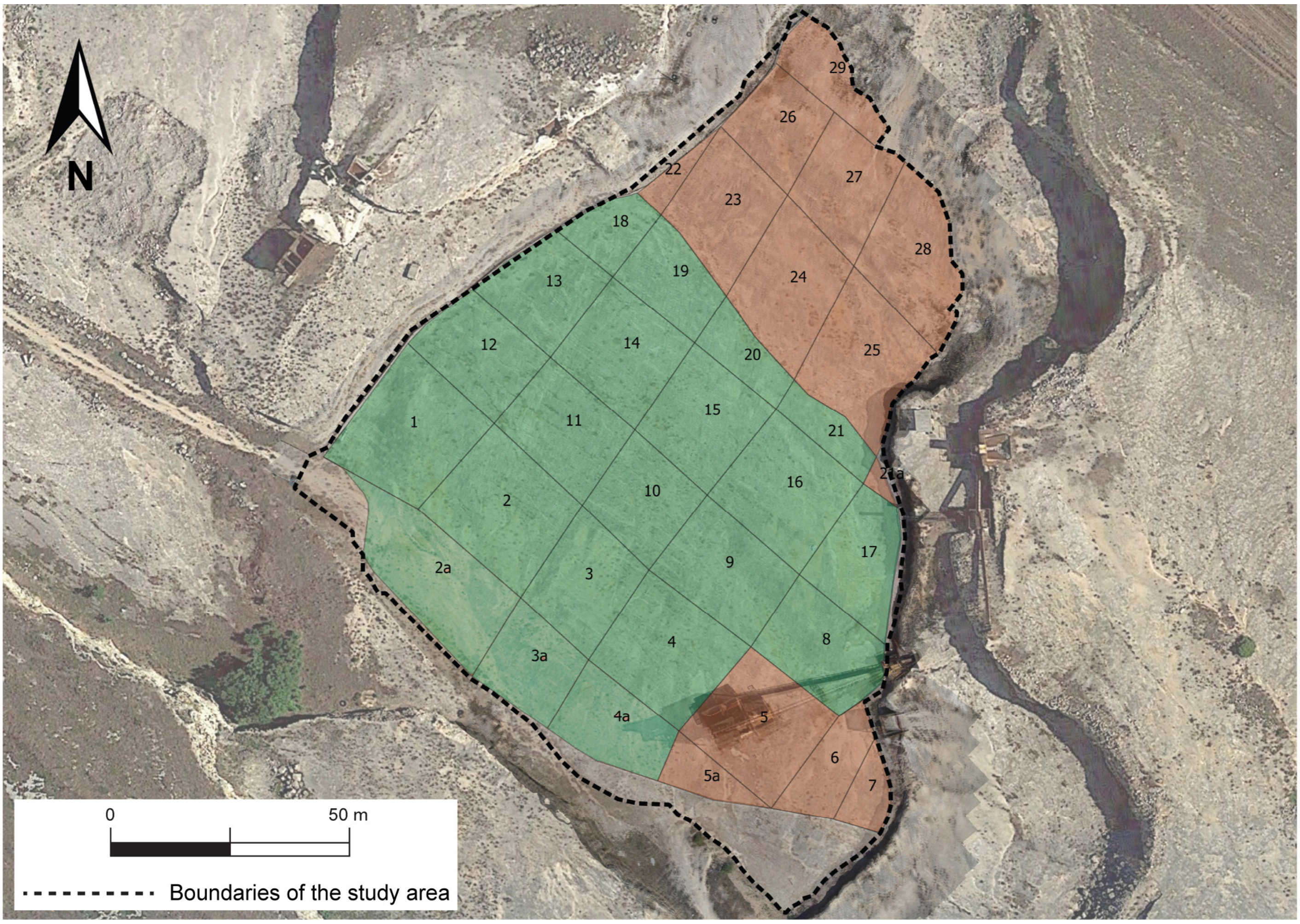

Fig. 2 - Scheme showing the partitioning of the palaeosurface cropping out at the "Cava Pontrelli". In green: sectors fully cleaned and surveyed; in red: sectors partially cleaned and surveyed.

four steps: i) cleaning of the surface (Fig. 3A); ii) ichnological survey (Fig. 3B), supported by using close-range photogrammetry (Fig. 3C); iii) aerial photogrammetric survey of each sector by means of sUAS (small Unmanned Aerial Systems; Fig. 3D); iv) graphical digitization and georeferencing ichnological data obtained by aerial-based photogrammetry.

The track-bearing horizon was carefully cleaned, with the aim to remove debris from each footprint and surrounding surface. After a preliminary manual cleaning, carried out with geological hammers, stone chisel, and brushes, to remove the coarse and cemented component of debris, a mechanical cleaning for the fine component was performed with an industrial vacuum cleaner (Fig. 4).

Morphological interpretative sketches of each track were subsequently drawn with coloured chalks, to highlight: i) the outline of the single tracks and, if any, the anatomical characters of the trackmaker *autopodium*; ii) deformations of the substrate, due to dinosaur trampling; iii) deformations of the footprints, due to the mud-collapse; iv) tracks displacement due to tectonics. Two different track-bearing layers were identified, and several sectors are characterised by undertracks (deformed layer beneath the true track; Milàn and Bromley, 2006).

Twelve trackways were identified, mainly grouped into two different morphotypes. The main morphometric parameters were measured for each specimen, following the methods proposed by Leonardi (1987) and Thulborn (1990).

Close-range photogrammetry was carried out on the best-preserved tracks and two trackways, to gain more accurate morphological information and anatomical details about the trackmaker *autopodium*. For data acquisition, each track was photographed turning through 360° around it, with four different vertical points of view with respect to the surface horizon (i.e., 10°, 30°, 60°, and 90°), attempting to maintain a 1 m distance from the footprint (Fig. 3C and Fig. 5A). For each detected track about 40 images were taken, using the digital single-lens reflex camera Canon EOS 1300D,

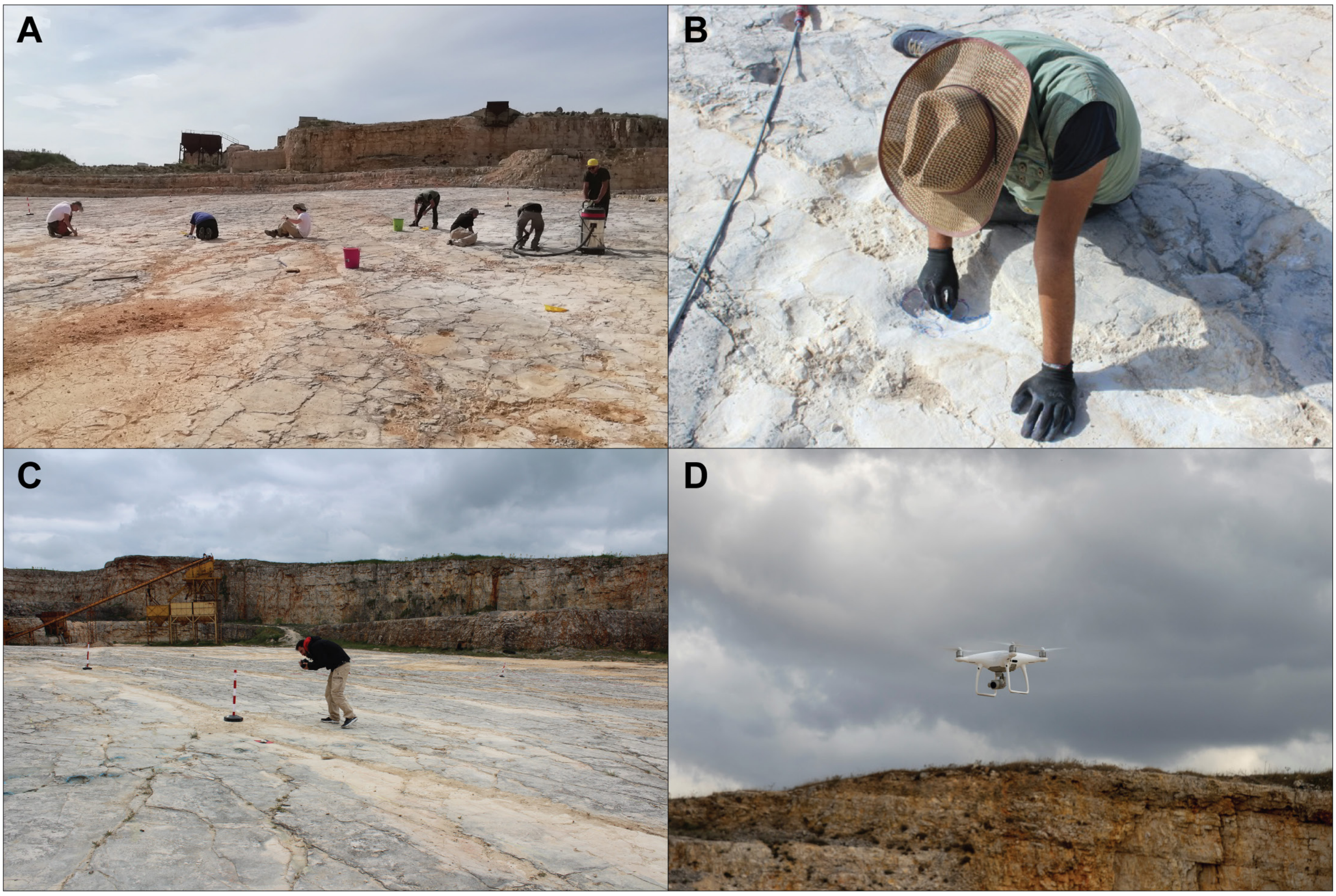

Fig. 3 - Ichnological survey: A) surface cleaning phase; B) morphological interpretative drawing; C) close-range photogrammetry; D) aerophotogrammetric survey performed by using the drone DJI Phantom 4 Pro.

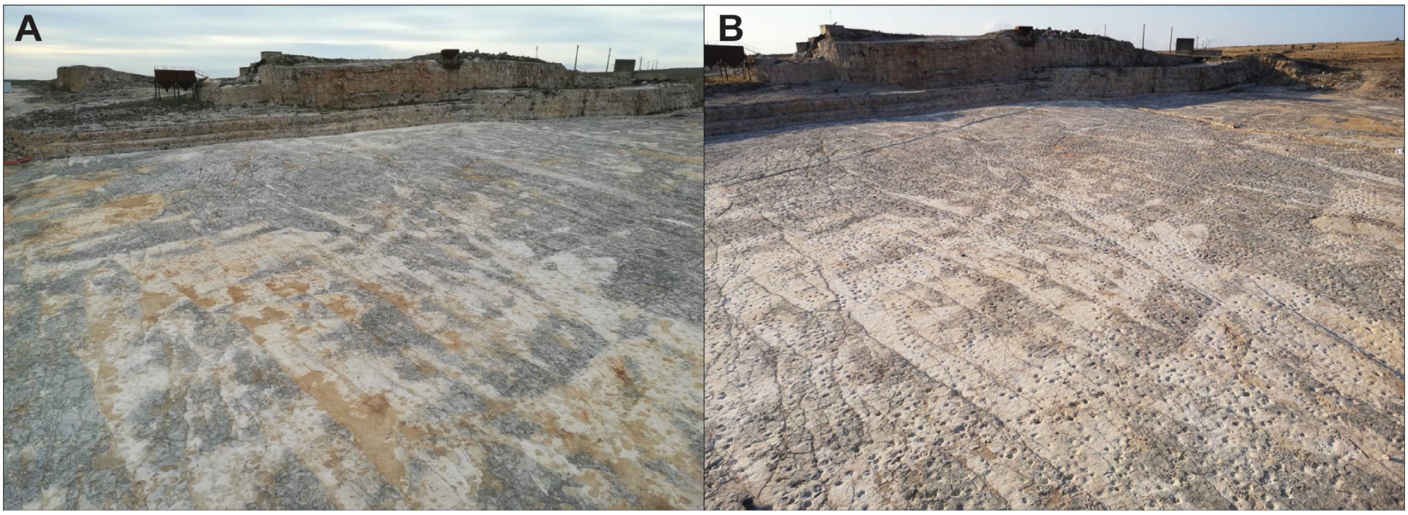

Fig. 4 - Comparison of the track-bearing surface before (A) and after (B) cleaning.

equipped with an 18.0 Megapixel CMOS (APS-C) image sensor and EF-S 18-55 mm lens.
The SZ DJI Phantom 4 Pro quadcopter was used to perform the low-altitude photogrammetric survey of the Altamura site. It is a small Unmanned Aerial Vehicle (sUAV) equipped with all systems for automatic flight and with a camera shooting at 4K up to 60 frames per second and capturing at 20 Megapixel. It was piloted by

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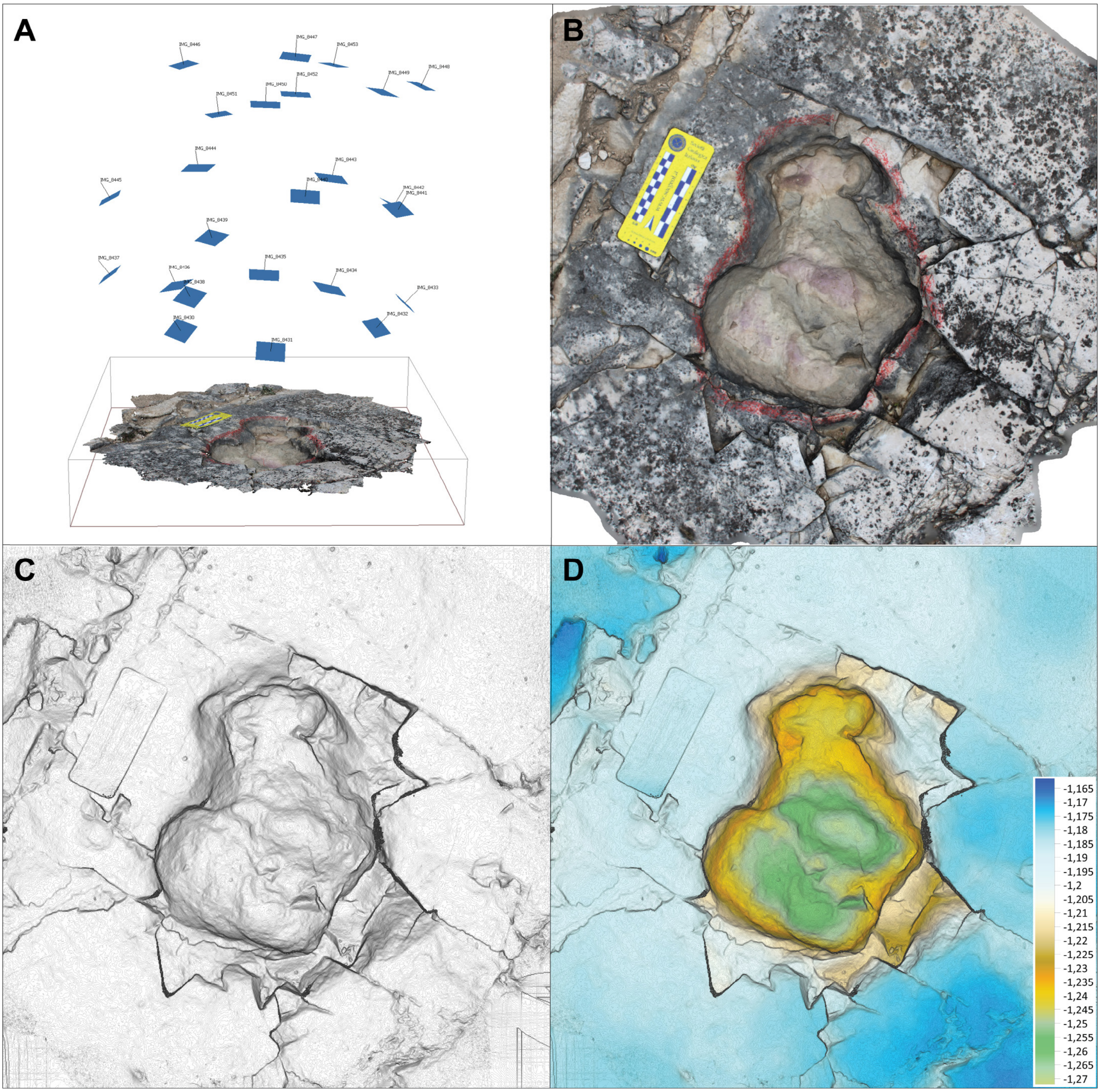

Fig. 5 - Photogrammetric model of ACDL99/3-10, holotype of *Apulosauripus federicianus*: A) dense cloud showing camera shoots; B) 3D model; C) black and white contour map; D) color-coded contour map.

setting the ground station to the automatic Positioning mode (P-mode), in quarry sectors away from walls and other obstacles (e.g., quarry infrastructure) where the GPS signal was good, or to semi-automatic Attitude mode (A-mode), where the GPS signal was not strong enough and where the risk of collisions with obstacles was relevant. The drone operations were planned on a geo-referenced orthophoto showing the partition into sectors of the quarry surface (Fig. 2). The orthophoto was imported on the DJI Ground Station (GS) Pro app installed on an Apple iPad. Flight missions were set up on the app by choosing a front overlap ratio of 80% and a lateral overlap ratio of 60%. The flight heights were set in order to obtain 3D models with higher resolution in those sectors where the footprints are better preserved and show greater density. Specifically, a flight height of 5 m was set up for sectors 1 to 4 and 8 to 21, 2a, 3a, 4a, while a height of 10 m was set up for sectors 5, 5a, 6, 7, 21a, and 22 to 29. A flight height of 20 m was set up for the survey of the entire surface. The flight path and the number of waypoints were automatically calculated by the app based on the above parameters. In addition, the "hover and capture at a point" mode has been set for 5 m height flights to achieve stable shooting and better image resolution. In this mode, the number of waypoints required for each mission (i.e., for each sector) was huge, approximately 400 per sector, and the time required to complete each mission was relatively long, approximately 1.5 hours. Finally, the "capture at equal distance interval/time interval" mode was selected for flights at 10 m and 20 m. In this mode, flight speeds and the camera shutter interval were calculated automatically according to the camera features and the altitude (resolution) settings. As a consequence, the number of waypoints was significantly less (about 100-120 per sector) and the time to complete each mission was around 20-25 minutes. All the aerophotogrammetric surveys were geo-referenced by means of a differential GPS survey in Real-Time Kinematic (DGPS/RTK) on several ground targets. Moreover, fixed Ground Control Points (GCP) were previously identified and geo-referenced in the quarry and used to verify the accuracy of the aerophotogrammetric survey.

Both close-range and aerial-based photogrammetric images processing was performed with the software Agisoft Photoscan ® Professional v. 1.4.5, following the procedure established by Mallison and Wings (2014). The workflow followed these steps: i) image import in the software; ii) aligning the photos to produce a sparse point cloud; iii) marker addition for geo-referencing (aerial-based survey) and for in-program scale bar creation (close-based survey); iv) dense point cloud generation based on identified homologous points on the aligned images; v) polygon mesh generation; v) orthophoto generation and export in .tiff format.

The obtained 3D model for close-range photogrammetry, oriented on x, y and z axes, was then imported as a text file on the software Golden Software Surfer ® 16. A grid file was produced, using a kriging algorithm to interpolate point data of the text file for a complete coverage of the model surface. The final step was the achievement of a 3D colour-coded model (DEM) with contour lines, with the aim to emphasise the morphologies of the track surface (Fig. 5).

The high-resolution orthophotos gained with the aerial-based photogrammetric survey (Fig. 6) were subsequently used for vector drawing of each single footprint, highlighted with coloured chalks in the field, by means of Adobe Illustrator, to produce an accurate geothematic map of the entire dinoturbated surface. Footprints filled by sediment were kept distinct with a striped background.

Geological setting

The Altamura tracksite is located in a disused quarry ("Cava Pontrelli"; Figs 1 and 7) close to "Masseria Pontrelli", 4 km east of Altamura (approximately 50 km south of Bari), at km 6 of the Road SP 235 connecting the towns of Altamura and Santeramo in Colle.

The track-bearing surface belongs to the Upper Cretaceous inner platform carbonate succession of the Calcare di Altamura, a formation regionally Coniacian-Maastrichtian in age. This unit is part of the "Calcari delle Murge e del Salento" group (Ciaranfi et al., 1992), is about 1 km thick (at regional scale) and recorded the aggradation of shallow-water carbonates in the Apulia Platform (e.g., D'Argenio, 1974; Ricchetti et al., 1988; Spalluto, 2012), one of the Periadriatic Carbonate Platforms (*sensu* Zappaterra, 1990; 1994) in the western sector of the Neotethys. The Apulia Carbonate Platform has been considered for several decades as a Bahamian-type isolated platform, but the discoveries of several dinosaur footprints in some bed surfaces of the carbonate succession led to a deep palaeogeographic revision, suggesting the presence of bridges between Neotethys platforms and the main continents to justify the migration occurrence of these terrestrial vertebrates (Bosellini, 2002; Petti, 2006; Nicosia et al., 2007; Zarcone et al., 2010; Randazzo et al., 2021).

The carbonate succession cropping out in "Cava Pontrelli" is made up of about 50 m thick peritidal and shallow subtidal facies associations showing a shallowing-upward cyclic arrangement (Iannone, 2003). This limestone succession has been object of several structural research studies aimed at characterizing the secondary porosity due to brittle discontinuities of tectonic origin (Korneva et al., 2014; Lavenu et al., 2015; Laurita et al., 2016; Panza et al., 2016, 2019; Zambrano et al., 2016). So that, while fracturing has been abundantly characterised, further structural details about the major faults are appropriate since no agreement on the exact geometry and kinematics of these faults still exists in the literature. Therefore, the original structural data collected in "Cava Pontrelli" (AA.VV., 2020) reveal that the carbonate succession gently dips overall to the SSW, and is affected by two major NE-dipping, high-angle faults, the northeastern and southwestern ones, dominated by dip-slip kinematics (Figs 8 and 9A-B). Throws of 10 m and 20 m have been estimated for the northeastern and southwestern faults, respectively, based on displaced stratigraphic markers, such as a characteristic bed of intraformational breccia (Fig. 9A-B), and the dinosaur footprint surface, the latter delimited in plain view by these two major faults (Fig. 8). The fault zone of each major fault shows a thickness of ca. 15 m (e.g., Fig. 8);

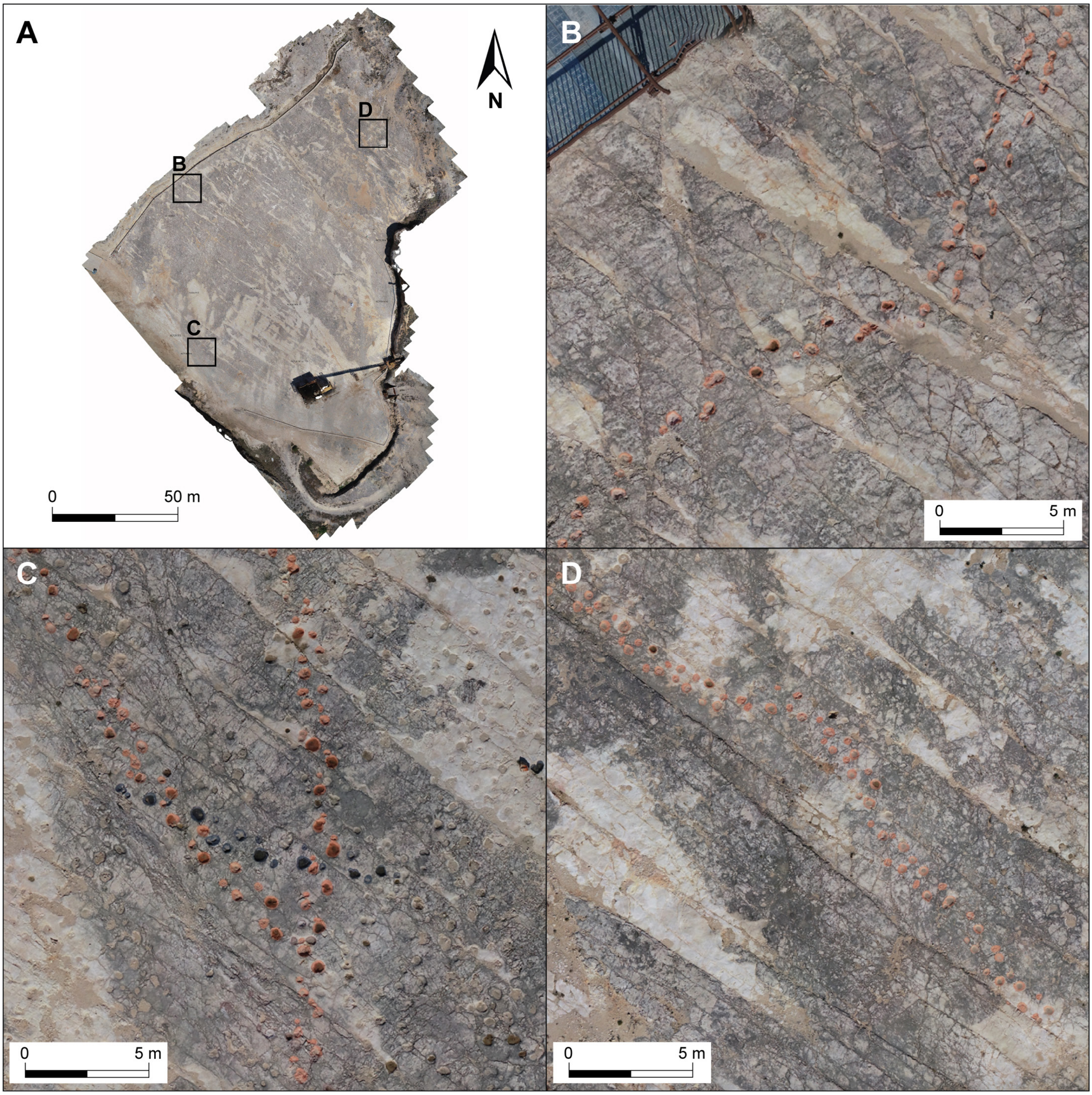

Fig. 6 – Selected orthophotos from the “Cava Pontrelli”: A) the whole track-bearing surface; B) close-up of trackway ACDL99/1, pointing towards NE; C) close-up of the crossroad of trackways ACP2019/5 (NW directed), ACP2019/6 (WNW directed), and ACDL99/2 (N directed); D) close-up view of trackway ACP2019/9, oriented towards NW.

it practically corresponds to the damage zone, which is dominated by intense fracturing (Fig. 9A-C) and includes the fault core, the latter characterised by the presence of fault breccia (Fig. 9D).

The biostratigraphic study of the lower portion of the succession cropping out in the quarry, including the track-bearing horizon, allowed the identification of a well-diversified benthic microfossil assemblage: *Accordiella conica* Farinacci 1962, *Rotalispira scarsellai* (Torre 1967), *Moncharmontia appenninica* (De Castro 1966), *Pseudocyclammina sphaeroidea* Gendrot 1968, *Scandonea samnitica* De Castro 1971, *Dicyclina schlumbergeri* Munier-Chalmas 1887, *Cuneolina pavonia* d’Orbigny 1846, *Nezzazatinella* sp., *Cuvillierinella salentina* Papetti and Tedeschi 1965, and *Thaumatoporella parvovesiculifera* (Rainieri 1922).

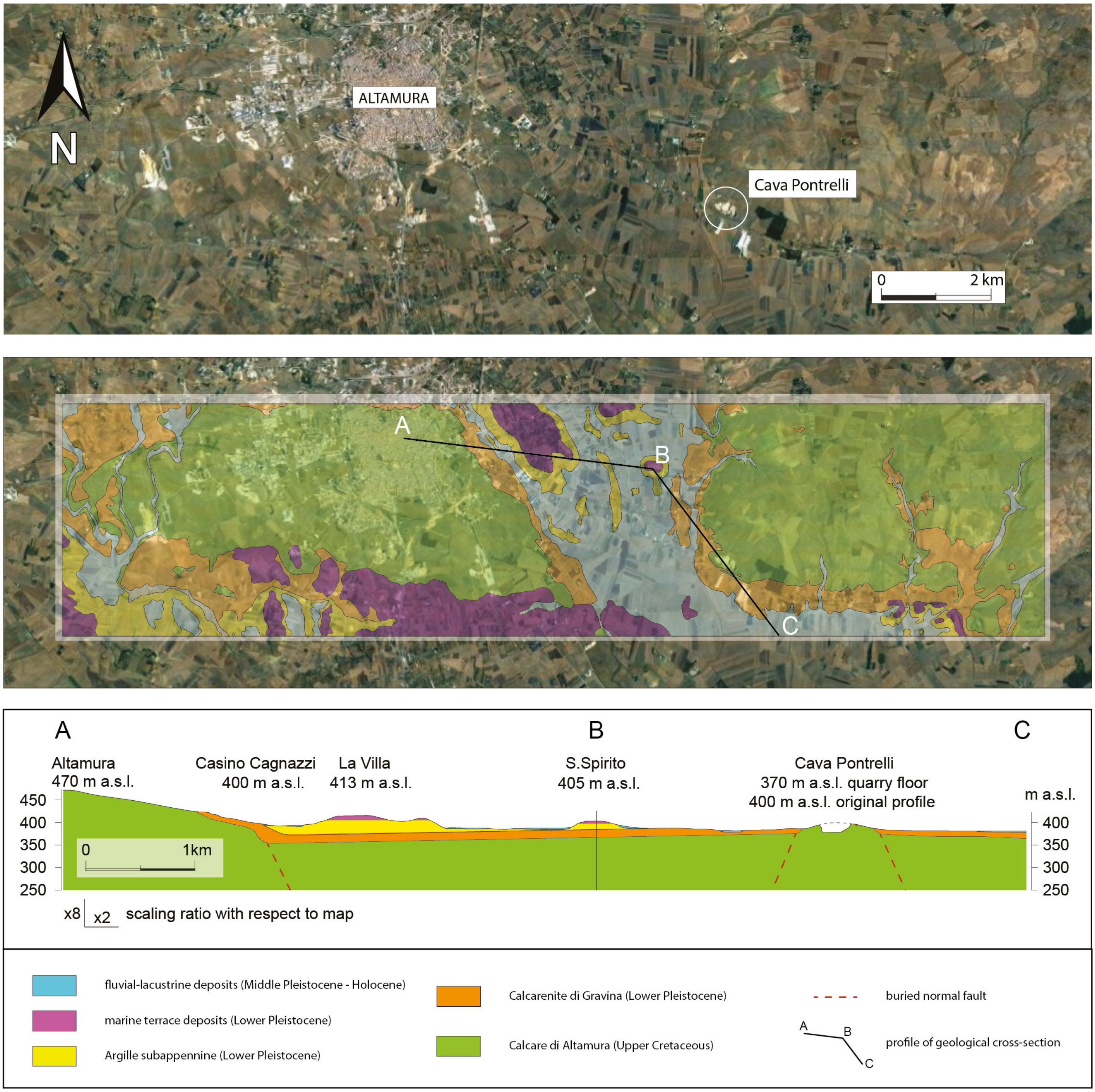

Fig. 7 - Schematic geological and structural map and subsurface stratigraphy of the tracksite area.

This benthic foraminiferal assemblage can be assigned to the *Accordiella conica* and *Rotalispira scarsellai* biozone of Chiocchini et al., (1994, 2012), whose age is referred to the Coniacian-early Campanian interval. Nevertheless, the occurrence of *Cuvillierinella salentina* allowed us to constrain the age of the Altamura section to early Campanian (upper part of the *Accordiella conica* and *Rotalispira scarsellai* Biozone) according to the recent revision of the stratigraphic distribution of this taxon in the western Mediterranean area (Fleury, 2016). Moreover, Schluter et al. (2008) assigned a Campanian age to the type locality of this benthic foraminifer in Salento (Cava Cocumula, Poggiardo) modifying the original late Santonian attribution (Papetti and Tedeschi, 1965). The analysis performed for calcareous nannofossil study evidenced the occurrence of several barren samples mainly due to the environmental setting. However, very impoverished and poor preserved assemblages in a few samples, mainly composed of very rare specimens of Late

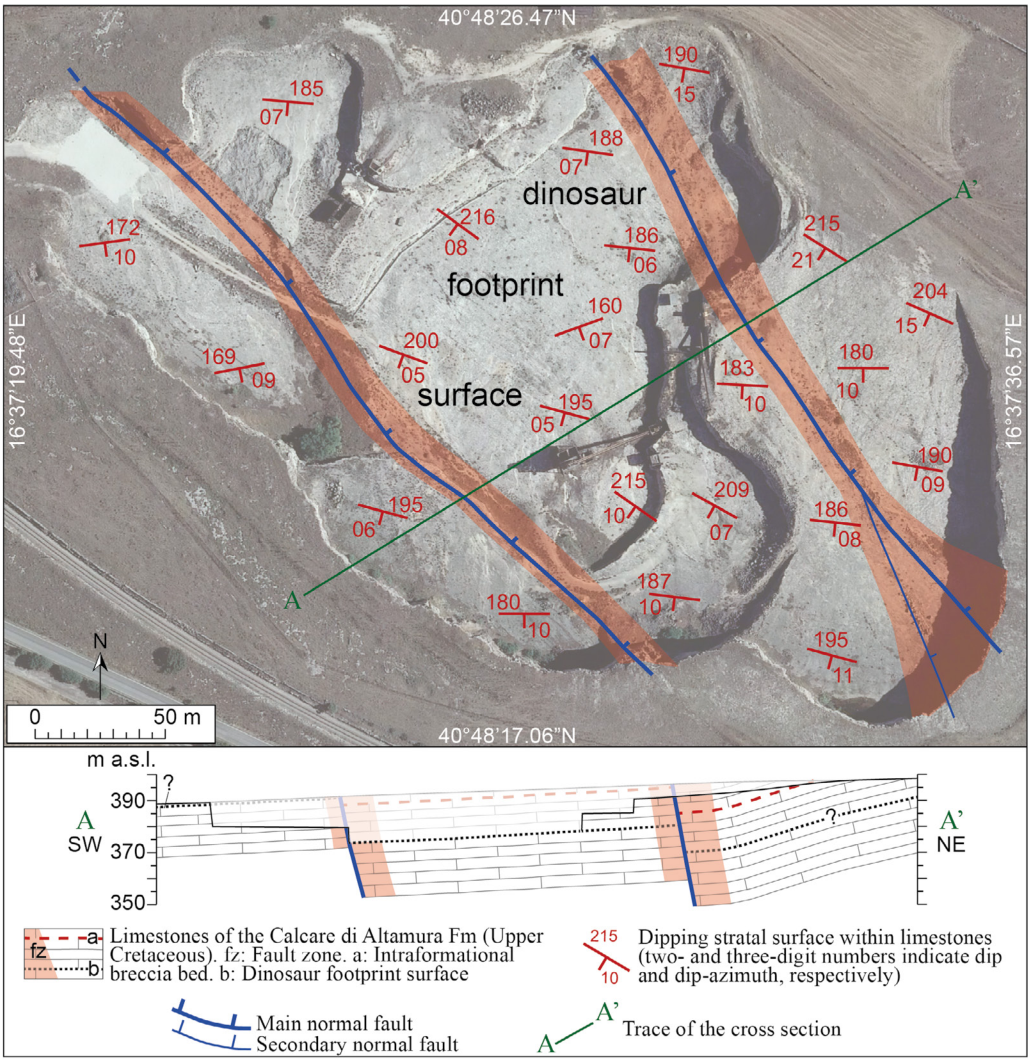

Fig. 8 - Structural sketch-map of the "Cava Pontrelli" and cross-section.

Cretaceous taxa (*Micula*, *Quadrum*, *Lucianorhabdus*, *Prediscosphaera*, *Watznaueria*), highlighted the presence of *Micula staurophora* (Gardet 1955), *Lucianorhabdus* cf. *cayeuxii* Deflandre 1959, *Quadrum gartneri* Prins and Perch-Nielsen 1977, *Calculites obscurus* (Deflandre 1959), *Quadrum gothicum* (Deflandre 1959). These species indicate an age not older than late Santonian - early Campanian (Burnett, 1998) that is consistent with the early Campanian inferred from the benthic microfossil age-assignment.

Map description

The geothematic map of the Altamura tracksite (see Electronic Supplementary Material) shows the whole dinoturbated surface, delimited by the quarry walls, in addition to the anthropogenics built during the quarrying activities and the herein described project. The scale map is 1:200.
The extremely high degree of trampling is highly appreciable in the map (with 13 footprints per m^2 on average), although the density is variable (Fig. 10): the surface is more intensively interested by dinoturbation starting from sectors 2a, 2, 11, 14, and 19, with a maximum degree of trampling in sectors 3a, 3, 10, 15, 20, 4a, 4, 9, 5 and 8. The area covered by sectors 1, 12, 13, and 18 is neatly the least dinoturbated, despite the occurrence of a long quadrupedal trackway (i.e., ACDL99/1). Despite the exceptional degree of trampling, about 600 footprints are arranged in twelve quadrupedal trackways, without preferred orientation (Fig. 11). Four trackways were already known (i.e., ACDL99/1, ACDL99/2, ACDL99/3, and ACDL99/4; Nicosia et al., 1999b; Petti, 2006), whereas eight trackways were discovered in this study. The new quadrupedal trackways were classified by the acronym ACP (= Altamura Cava Pontrelli), the year (i.e., 2019), and a sequence number starting from 5 (e.g., ACP2019/5). Below a synthetic description of the recognised dinosaur trackways and their main morphometric parameters is provided. The detailed results of the ichnological study will be the subject of a forthcoming paper.

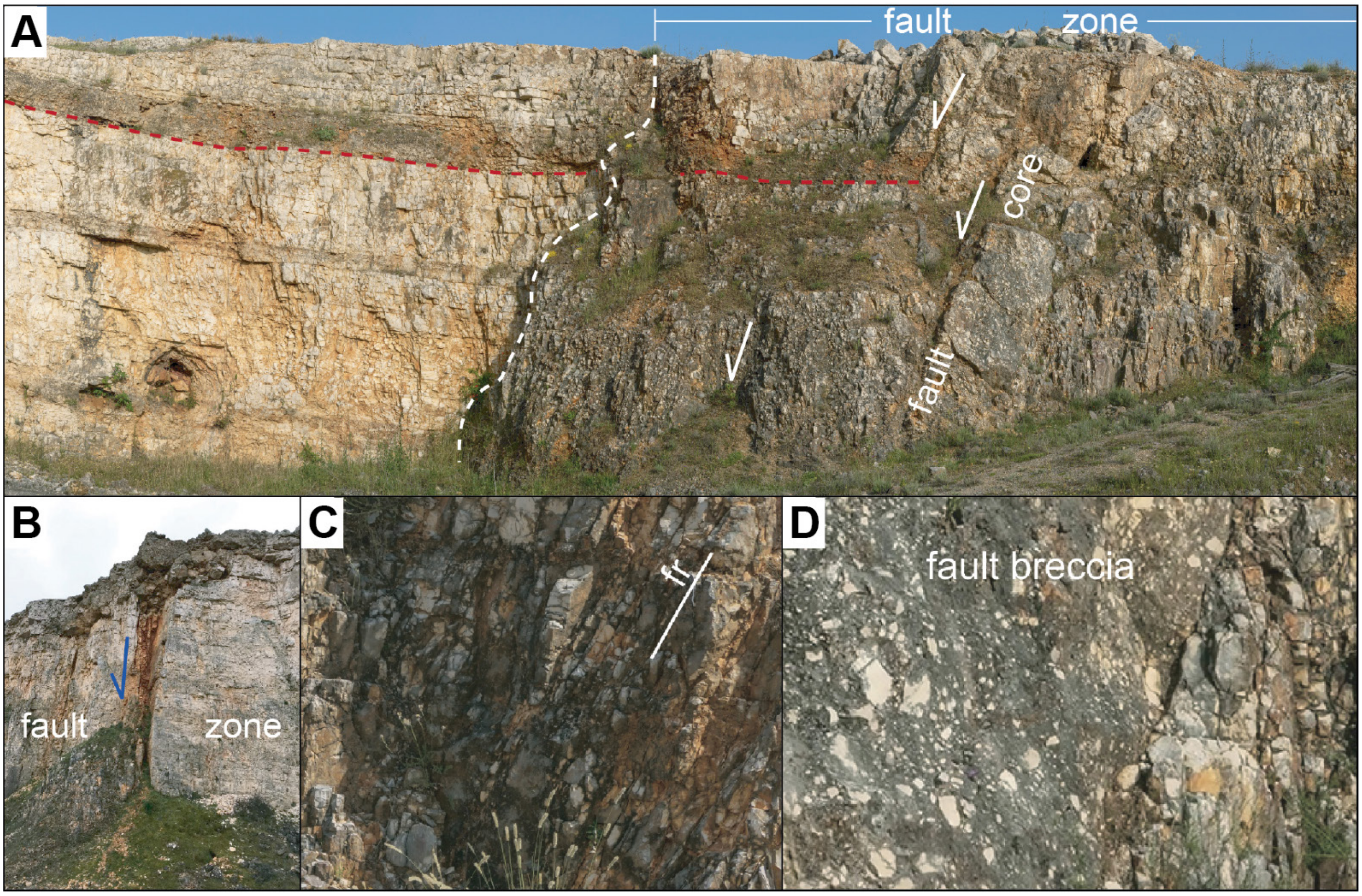

Fig. 9 - A) Northeastern major fault dominated by dip-slip kinematics; the red dashed line indicates the base of the bed made of intraformational breccia within the limestones succession. The height of the wall is about 5 m; B) southwestern major fault, dominated by dip-slip kinematics, affecting the limestones succession. The height of the wall is about 8 m; C) fractures (fr) in the limestones involved in the damage zone. The width of the wall is 1 m; D) fault breccia within the core of the northeastern major fault. The width of the wall is 1 m.

The degree of preservation of footprints is highly variable, but most of the tracks are poorly preserved (value 1 of the numerical scale proposed by Belvedere and Farlow, 2016). Digit and ungual marks are not always recognisable and in most of the specimens, the only general outline is preserved. The best-preserved trackways display distinguishable *manus-pes* couples on which digit traces are clearly appreciable. It is also worth noting the lack of well-defined raised rims in all of the surveyed footprints.The trackway ACDL99/1 (sectors 1,12 and 13) is a 50 m long, and 65 cm (on average) wide quadrupedal trackway composed of 75 steps (i.e., *manus-pes* couples) and directed towards SE. It is interrupted for a few meters and the lack of the *manus-pes* couples between steps 36 and 37 is due to the partial outcropping of the upper stratigraphic horizon. ACDL99/1 is attributed to a hadrosaur trackmaker, with an estimated hip height of about 1.16 m and a length of 4.6 m. The ACDL99/2 (sectors 3a, 2, and 2a) is the longest trackway of the ichnosite (about 40 m), constituted by 88 *manus-pes* sets and oriented towards N/NE. The total width is 57 cm on average. The most suitable trackmaker is a 4.2 m long hadrosaur, with a hip height of 105 cm. The ACDL99/3 (sector 10), including the holotype of ichnospecies *Apulosauripus federicianus* Nicosia, Marino, Mariotti, Muraro, Panigutti, Petti and Sacchi 1999, is about 6 m long and 67 cm wide on average, composed by 12 quadrupedal steps and directed towards W/NW. It was produced by a hadrosaur about 4.8 m long, whose hip height was around 120 cm. The ACDL99/4 trackway (sector 25) is about 10 m long and 55 cm wide on average. It is represented by 21 *manus-pes* couples and is oriented towards NW. The putative trackmaker is likely a 3.3 m long ankylosaur with a hip height of 84 cm. The ACP2019/5 (sectors 2a and 3a) is 25 m long and 65 cm wide, pointing towards N/NW. It is composed of 45 quadrupedal sets, produced by a hadrosaur with a hip height of 108 cm and reaching a total length of about 4.3 m. The ACP2019/6 (sector 3a) crosses the trackways ACDL99/2 and ACP2019/5, directed towards E/SE. It is represented by 7 *manus-*

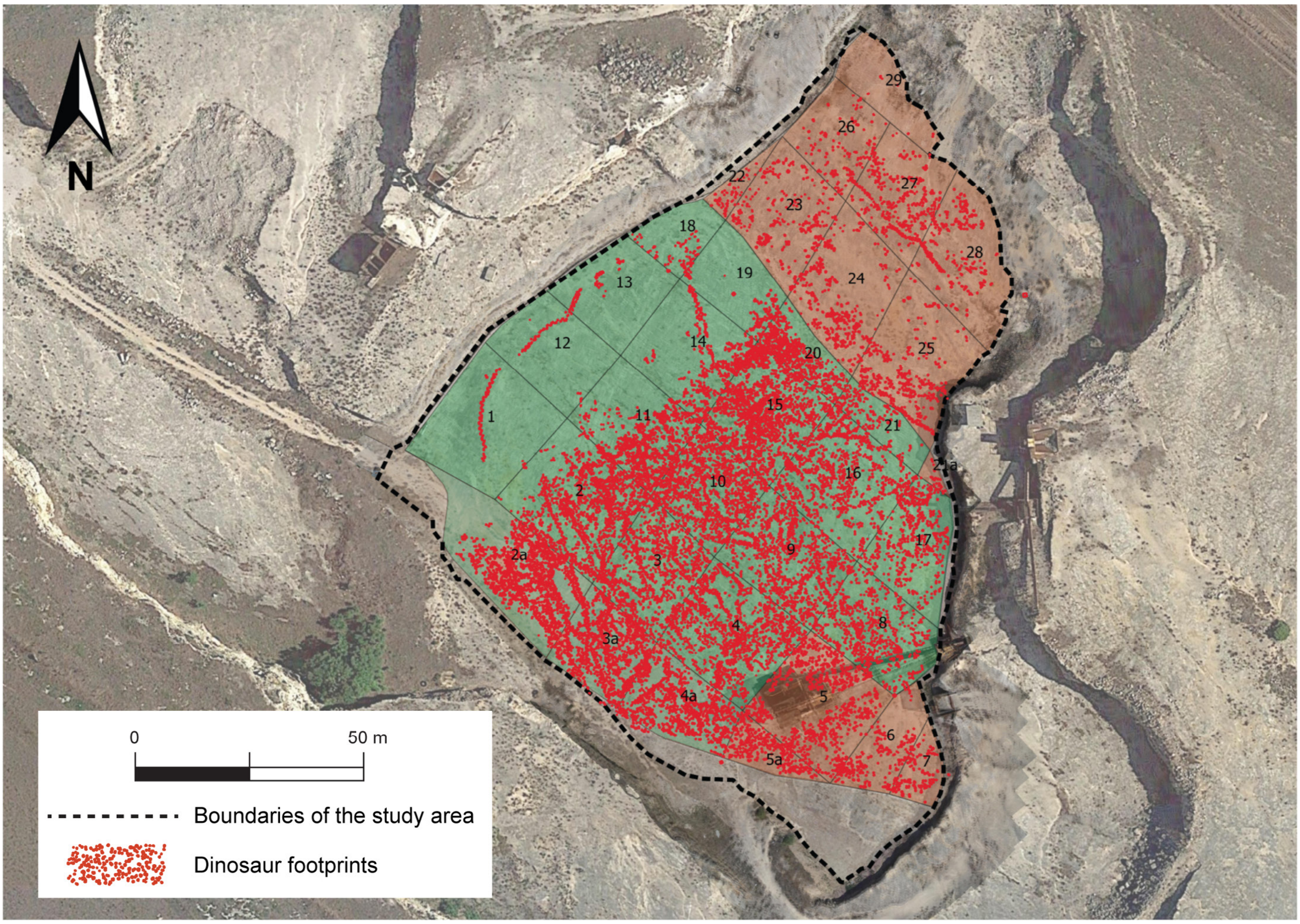

Fig. 10 – Dinosaur tracks distribution on the “Cava Pontrelli” surface.

pes sets: its total length is 6 m, while the total width is up to 39.5 cm. The putative trackmaker is a 4.7 m long hadrosaur, with an average hip height of 117 cm. The ACP2019/7 (sector 3a) is a short trackway, less than 2 m long and 61 cm wide on average, whose origin lies between the 10th and 11th sets of ACDL99/2. It is composed by 4 *manus-pes* couples and is attributed to an ankylosaur trackmaker with a hip height of 117 cm, likely 3 m long. The ACP2019/8 (sector 9) is about 5 m long, 75 cm wide on average, and is oriented towards E/SE. Nine quadrupedal sets compose the trackway, attributed to a 4.8 m long hadrosaur, whose hip height is estimated at around 122 cm. The ACP2019/9 (sectors 27 and 28) is a 15 m long, sinusoidal trackway directed towards NW, whose total width is about 50 cm. It is represented by 39 *manus-pes* couples, likely produced by an ankylosaur with a hip height of 63 cm and a body length of 2.5 m. The ACP2019/10 (sector 17) is a quadrupedal trackway composed of 13 steps, pointing towards S/SE. Its total length is 7.5 m, while the total width is 75 cm on average. The most suitable trackmaker is an ankylosaur with a hip height of ≈ 90 cm and a length of 3.6 m. The ACP2019/11 (sector 16) is composed of 5 *manus-pes* sets. It is 3 m long and about 70 cm wide and is directed towards SW. It was likely produced by an ankylosaur trackmaker with an estimated hip height of 81 cm and a length of 3.2 m. The ACP2019/12 (sector 4) is a short trackway (about 1.5 m long and 60 cm wide), directed towards SW and composed by 4 manual and pedal impressions. It is attributed to a 3 m long ankylosaur, with a hip height of about 75 cm.

The twelve trackways were highlighted by different colours on the map (see also Fig. 11). The tracks detected with close-range photogrammetry were represented in yellow, associated with the acronym of 3D models

The achievement of the geothematic map permitted to accurately assess the number of tracks on the surface, amounting to about 26,000 specimens with a maximum dinoturbation index of about 74.2 % (*sensu* Lockley and Conrad, 1989) and a heavy degree of trampling (about 13 footprints/m^2; see Lockley, 1991).

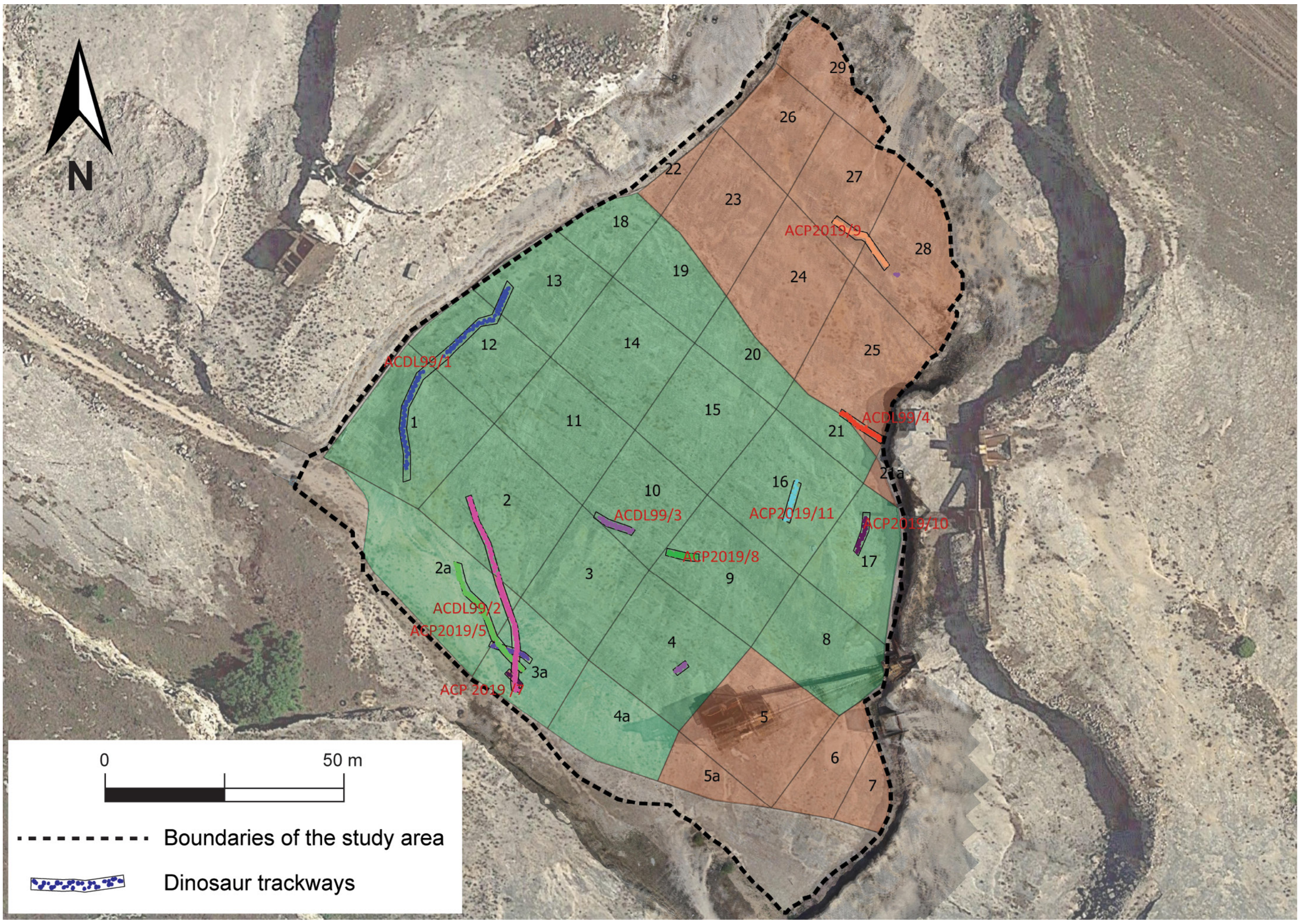

Fig. 11 – Distribution of the twelve recognised dinosaur trackways.

The Geosite

The studied surface falls within the boundary of the "Alta Murgia" National Park, corresponding to the highest part of the Murge, which is a large uplifted karstic area bounded and mainly crossed by normal faults (Iannone and Pieri, 1982; Pieri et al., 1997; Tropeano et al., 1997; Festa, 2003). The Murge is a remnant part of Adria (Ricchetti et al., 1988; van Hinsbergen et al., 2014; 2020), the plate "squeezed" between Africa and Eurasia since these two continents began to converge. The deformed Adria rocks are widely distributed in the orogens surrounding the Mediterranean Sea, and in many newspaper and magazine articles as well as on web videos, Adria is described as "a lost continent". Even if this definition is "scientifically incorrect", the idea of the lost continent is very attractive, also because the Murge is a region where a small part of this lost continent still survives ("the last piece of the lost continent"). Following both this mediatic "leitmotiv" and solid scientific grounds the executive of the "Alta Murgia" National Park decided to propose the inclusion of park area in the network of the UNESCO Global Geoparks.

Apart from the worldwide geological uniqueness, being the area an *in situ* remnant of the Adria Plate, the international value of the proposal is enriched by the occurrence of several geological singularities, one of which is the studied largest surface in the world with Upper Cretaceous dinosaur tracks. It represents a very attractive site both for geotourists and geoscientists and has been included in the geosites land registry of the Puglia Region (http://193.206.35.15/geoportal/index.php) (Mastronuzzi et al., 2015) and in Italian Geosites Inventory of ISPRA (id: 1717; http://sgi.isprambiente.it/GeositiWeb/default.aspx?ReturnUrl=%2fgeositiweb%2f).

Discussion

Aerial-based photogrammetry uses wide-angle images and georeferenced points on the ground to recreate the geometry and the topography of large areas in a digital three-dimensional model. The resolution and scale of

the model substantially depend on the focal length of the camera lens and flight height (Matthews, 2008). The adoption of these techniques in ichnological studies has increased dramatically in the last decade to the point of becoming almost routine (Romilio et al., 2017; Citton et al., 2017; Petti et al., 2018; Xing et al., 2020; Cónsole-Gonella et al., 2021 and references therein). Initially developed by using helicopters, gliders, or hot-air balloons, on which digital cameras were installed (Breithaupt et al., 2004; Romilio et al., 2017), aerial-based photogrammetry has recently undergone a qualitative evolution, due to the use of sUAS. The application of this technology, based on the acquisition of high-resolution aerial orthophotos, allows the achievement of detailed maps of a track-bearing surface, as well as the ichnological study where the topographical conditions do not allow direct access to the track-bearing surface (Citton et al., 2017; Petti et al., 2018). The use of drones (a quadcopter DJI Phantom 4 in the present case) results in an extreme accuracy of the documentation (i.e., orthophotos and 3D models obtained from the aerial survey), with affordable working cost and rapid acquisition and processing phases.
The adoption of aerial-based photogrammetry by means of sUAS allowed us to quickly carry out the 3D mapping of the Altamura tracksite. It is likely the richest dinosaur tracksite in the world, with a total number of about 26,000 footprints, about 12,000 more than the famous Cal Orck'o ichnosite in Bolivia (Meyer et al., 2021 and references therein). The Altamura ichnosite can be thus potentially an excellence for the impressiveness of its palaeontological record and should go through a process of valorisation as performed in numerous dinosaur tracksites such as the St. George Dinosaur Discovery Site at Johnson Farm in Utah (Milner and Lockley, 2006) and the La Rioja in Spain (Torices et al., 2020 and reference therein).
The obtained map led to shedding light on the exceptional impact of the Altamura surface in the overall framework of the Cretaceous palaeogeography in the Periadriatic region, confirming an ecological scenario in which the Apulia Carbonate Platform hosted well-developed dinosaur communities in a diversified ecosystem.

Conclusions

The first detailed geothematic map of the Altamura ichnosite represents an essential tool for ichnological studies, by which it is possible to: i) have a useful overview of the whole track-bearing surface; ii) perform accurate measurements of trackways morphometrics parameters; iii) estimate the dinoturbation index and the degree of trampling.
Furthermore, the geothematic map and the orthophotos will permit planning activities for future reliable strategies of long-term conservation, valorisation, and public dissemination of this palaeontological heritage.
The 3D models carried out by means of close-range photogrammetry and the 3D mapping performed with drones will be available for all the specialists interested to study the Altamura ichnoassemblage, with the incontrovertible advantage of being able to consult electronically the scientific material (without the need to access to the quarry) for their palaeontological research.
The achievement of accurate high-resolution models freeze the state of preservation of the dinoturbated horizon, scientifically recording the ichnological data (e.g., objective morphologies and morphometric parameters of the best-preserved tracks and all the trackways) and allowing to monitor the weathering on the quarry surface by periodically repeating aerial surveys with sUAS (multi-temporal monitoring).
All the obtained products can represent useful tools to develop educational programs (e.g., virtual tour, exhibition, interactive panels) and support a museum project, focused on the complete valorisation and management of the site. They can be essential for tracks preservation but also to increase the public awareness about this unique geopalaeontological heritage, in order to promote an excellence of the territory, encouraging the development of a sustainable geotourism through tracksite outdoor musealization.

Electronic supplementary material

This article contains electronic supplementary material (Geothematic map of the Altamura tracksite).

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